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Thermal comfort comparison and evaluation in different climates

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A B S T R A C T

The growth of cities combined with an increased urban density leads to considerable thermal stress and connected health risks. In this situation it is important to develop benchmarks for thermal comfort, which can guide planners to a better urban design. The aim of this study is to present the results of investigations carried out in Belo Horizonte (Brazil, tropical climate), in Kassel and in Freiburg (Germany, temperate climate). The same method was used in all cities in order to compare the limits of thermal stress and to study the response of pedestrians regarding the subjective evaluation of thermal sensation, when considering specific microclimate conditions. In each city, microclimatic data were measured simultaneously with administration of questionnaires, in squares that noticeably differ in relation to their thermal environment and their morphological parameters. The Physiological Equivalent Temperature Index (PET) was calibrated in each country. The results show that neutral range in Brazil is from 16 °C to 30 °C PET and that hot range starts at 32 °C PET. In Germany, neutral range is from 18 °C to 28 °C PET and hot range starts at 35 °C PET. The very hot category starts in lower values of the PET index in Brazil (36 °C) than in Germany (38 °C).

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1. Introduction

Thermal conditions in urban areas are physically influenced by urban structures such as building and settlement geometry, open spaces obstacles and surface materials (Oke, 1978; Katzschner, 2010). These urban features, associated with the climatic conditions, result in different microclimates, which must be assessed separately from the overall urban climate (Burt et al., 1982 quoted in Mayer; Höppe, 1987). In addition, for utilization of urban climatology results as one among the many foundations of urban planning, besides considering the microclimates themselves, it is important to consider the human being as a reference. This means that it is important to evaluate the urban microclimates linked with a thermophysiological approach in order to see how it influences the human thermal comfort (Mayer and Höppe, 1987).

Thermal comfort and its effects on human beings are better understood through thermal indices. The simple consideration of air temperature is not an adequate indicator. Thermal comfort indices represent the integrated effect on thermal sensation including all relevant variables influencing it. There are many possible combinations for the wide range of values of these variables that can provide similar or even the same answers to the numerical value of the index and, consequently, to human thermal sensation. For this reason, indices of comfort, which group the conditions that provide the same response, are used (Frota and Schiffer, 1995). The calibration of these indices aims to determine representative intervals of thermal comfort conditions and to predict thermal sensation according to an assessment scale.

There are two dominant factors affecting thermal sensations in outdoor settings. One is the mean radiant temperature and the other is wind speed. Higher wind speed seems to be negatively perceived by people living in temperate climates but positively perceived in warmer climates. However, considering the predicted increase of temperature due to global climate change and the findings from KLIMES Project (Mayer, 2008), wind is becoming more important also in temperate climate regions and should be taken into account in further planning.

There are several biometeorological indices available. In this study we have used the Physiological Equivalent Temperature index - PET (Höppe, 1999), based on the Munich Energy-balance Model for Individuals (MEMI). This model MEMI considers all the basic thermoregulatory processes besides the physical processes. The PET index was chosen due to three main reasons: the first one is that it is adapted to outdoor settings; secondly, it is internationally used which provides comparability; and thirdly, in addition to its wide use, several work groups continuously develop it, as shown by Salata et al. (2016).

PET index is used to describe the thermal conditions and includes meteorological parameters such as Mean Radiant Temperature (Tmrt), Air Temperature (Ta), Wind Speed (v) and Relative Humidity (RH). It is defined as "the physiological equivalent temperature at any given place (outdoors or indoors) and is equivalent to the air temperature at which, in a typical indoor setting, the heat balance of the human body (work metabolism 80 W of light activity, added to basic metabolism; heat resistance of clothing 0.9 clo) is maintained with core and skin temperatures equal to those under the conditions being assessed" (Höppe, 1999, p. 73). Matzarakis and Mayer (1996) correlated values of PET with thermal sensation and stage of stress for people of Central and Western Europe (Table 1).

Recently the relevance of methods based solely on thermophysiology has been questioned and social research, using questionnaires, has been developed in order to validate the comfort index against the

Table 1
Physiological equivalent temperature (PET), thermal sensation and stages of stress; internal heat production: 80 W, heat transfer resistance of clothing: 0.9 (Matzarakis and Mayer, 1996).

PET (°C)	Thermal sensation	Stage of stress
	Very cold	Extreme cold stress
4	Cold	Strong cold stress
8	Cool	Moderate cold stress
13	Slightly cool	Slightly cold stress
18	Neutral (comfortable)	No thermal stress
23	Slightly warm	Slightly heat stress
29	Warm	Moderate heat stress
35	Hot	Strong heat stress
41	Very hot	Extreme heat stress

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